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A VITAL EMBRACE FOR THE BIG ONE

Overview of Hernando Desoto Bridge Looking North

As we work our way towards fulfilling the Federal Highway Administration's goals and focusing on its "Vital Few" (safety, environmental stewardship and congestion mitigation), we must at times go deep beyond the surface. Overall, with most projects, we can see immediate positive results and impacts from our efforts. However, there are times when we must strategically plan for the forces of nature that we have no control over. Therefore, anticipating the unknown and recognizing what lies beneath can help increase the safety and mobility of many. The states of Tennessee and Arkansas have taken such a role that may not be known to most motorists within this region.

The Tennessee Department of Transportation (TDOT) along with the Federal Highway Administration (FHWA), and Arkansas State Highway and Transportation Department (AHTD) has joined together to provide a seismic retrofit on the well-traveled Hernando Desoto Bridge. Together, their objective is to minimize any potential closures that may affect the Interstate 40 in the event of an evacuation.

Elvis' Hometown Braces for "A Whole Lot of Shaking"

In Memphis, Tennessee, the Hernando Desoto Bridge, which carries Interstate 40 over the Mississippi River, sits over the southeast edge of the New Madrid Seismic zone. The New Madrid Fault System running 120 miles from Illinois to Arkansas is considered to be the highest earthquake risk in the United States outside the West Coast. In 1811-1812, the Great New Madrid Earthquake sent a series of shocks for five months, which rang church bells on the Eastern seaboard and was several times larger in magnitude than the San Francisco earthquake of 1905. Even today, the risk for a damaging earthquake is very high, and this risk increases with time as the stresses in the earth build.

"If a sizable earthquake were to occur, based on the fact that the closest alternate river crossing is Helena, AR (approximately 70 miles south) and the closest interstate river crossing is on Interstate 155 (approximately 95 miles north), TDOT and AHTD estimate that the resulting detour would pay for the initial seismic retrofit investment on the Hernando Desoto Bridge in only 40 days."

- Mr. Ed Wasserman, Director of the Structures Division at TDOT

The Hernando Desoto Bridge is one of only two Mississippi River crossings in the Memphis area. It is a vital link for transportation, commerce and defense needs. The bridge was designed and built in late 1960's with very little seismic protection and therefore would not be serviceable if a damaging earthquake occurred. After consideration of potential national and regional impacts resulting from closure of the I-40 Mississippi River Bridge, it became a high priority for the regional area and FHWA. TDOT and AHTD took action.

In June 1992, Imbsen & Associates, of Sacramento California was contracted to conduct a seismic evaluation, prepare retrofit design, and oversee retrofit construction of the Hernando Desoto Bridge.

The seismic retrofit also advances the FHWA "Vital Few" by alleviating congestion and maintaining public safety during and after a seismic event.

Seismic Performance Goals

Because of the importance of the Hernando Desoto Bridge, it was decided that the bridge must remain operational and serviceable after the maximum probable "Contingency Level Earthquake" which was established to be a 2500 year return period (or a 2% chance of occurrence in 50 years). It was recognized that the bridge inevitably would need to be closed and inspected after a major event; however, it was decided that closure of the bridge would be limited to 2-3 days. Lastly, it was determined that any damage found during inspection of the bridge would be required to be minimal and repairable under traffic.

Seismic Deficiencies

When the Contingency Level Earthquake is considered, the original design of the bridge has a vast number of seismic deficiencies. IAI-NEABS (Imbsen & Associates, Inc.-Nonlinear Earthquake Analysis of Bridges Systems), a three-dimensional analytical modeling computer program, was used to analyze the original structure and specify seismic deficiencies. The results showed several deficiencies, including overstressed truss members and connections, insufficient resistance in the deck in both transverse and longitudinal directions, excessive plastic hinges with poor confinement at the base of pier columns and webwalls (this could cause the bridge to collapse) and inadequate amount of reinforcing steel in the footings to resist rocking of the footing on top of the caissons and/or longitudinal seismic overturning. In addition, the joints and bearings were found to be inadequate. The existing expansion finger joints were determined to be unable to withstand the expected seismic displacements. The existing bearings were tall, poorly braced and have the potential to tumble over or displace laterally, which could cause bridge spans to drop.

Retrofit Design Strategies

Two retrofit strategies were considered.

• The first was the traditional "strength and ductility" retrofit strategy which takes the basic approach of adding strength to bridge components in order to transfer all loads through the entire system. This approach required extensive strengthening or complete replacement of numerous bridge components including the bearings, truss members and connections, bottom lateral bracing and connections, the entire deck system, pier columns, webwalls, footings and distribution blocks. The estimated cost of the seismic retrofit using the Strength and Ductility strategy of just the main channel spans quickly added up to more than $45 million.

• The second seismic retrofit strategy combines strength, ductility and isolation. Isolation bearing technology advances have currently made the use of isolation strategies an achievable alternative. In general, isolation strategies limit the structural stresses on the bridge components while potentially increasing displacements. The two types of isolation bearings considered for the Hernando Desoto Bridge were the friction pendulum bearing and the lead core rubber bearing. The Hernando Desoto Bridge was analyzed utilizing isolation bearings in place of the existing bearings, and the results showed a significant reduction of stress levels in both the superstructure and the substructure. The estimated cost of the seismic retrofit using the Isolation strategy for the main channels totaled to $27 million. This was about a 40% reduction in construction costs without compromising structural safety or serviceability.

FHWA, TDOT and the AHTD selected the Isolation strategy for the Hernando Desoto Bridge seismic retrofit design.

Design Features Overview
The final seismic retrofit design and PS&E (plans, specifications and estimates) of the Hernando Desoto Bridge were completed using isolation strategies. Major design features included: replacement of existing bearings with isolation bearings, footing strengthening, column strengthening, column cap enlargement (to accommodate new isolation bearings), webwall modifications which tie the top of the webwall to the columns, replacement or strengthening of bottom lateral bracing, strengthening of steel cross frames, replacement of existing finger joints with modular swivel expansion joints, and truss retrofit, which includes adding some members in order to brace the portal frame posts.

Description of Existing Bridge

The Hernando Desoto Bridge was originally designed for only wind forces; earthquake loads were not considered. The existing bridge is a total of 3.3 miles long and contains 164 spans, 160 piers, and 10 abutments.

• The main spans over the channel consist of two tied arch truss spans and five steel box girder spans.
• Each tied arch truss span is 900 feet long and is primarily made of built-up steel box sections. These spans are supported by piers, which are made up of 126 feet tall tapered concrete columns connected by a 6' thick webwall.
• The columns taper from a 14-foot diameter at the top to an 18-foot diameter at the bottom.
• The piers sit on distribution blocks and are supported by concrete footings on top of rectangular concrete filled steel caissons.
• The original bridge incorporated three steel plate finger expansion joints. Each joint allowed a maximum of 13 inches of longitudinal movement, but did not permit any transverse movement.
• The steel box girder spans are continuous and are located to the west of the tied arch spans. Of the five spans, two spans are 330-foot long and remaining three spans are 440-foot long.
• The spans are supported by piers, which are made up of tapered concrete columns varying in height and connected by a 4-foot concrete web-wall, which originally extended approximately 75% of the height of the column.
• The piers sit on distribution blocks and are supported by concrete footings on top of a concrete seal and steel H-piles.
• The approaches and connecting ramps to the West consist of pre-stressed concrete I beams and steel plate girders. To the east, the approaches and connecting ramps consist entirely of steel plate girders. These spans are supported primarily by multi-post bents. The posts/columns bear on spread footings on top of concrete piles.

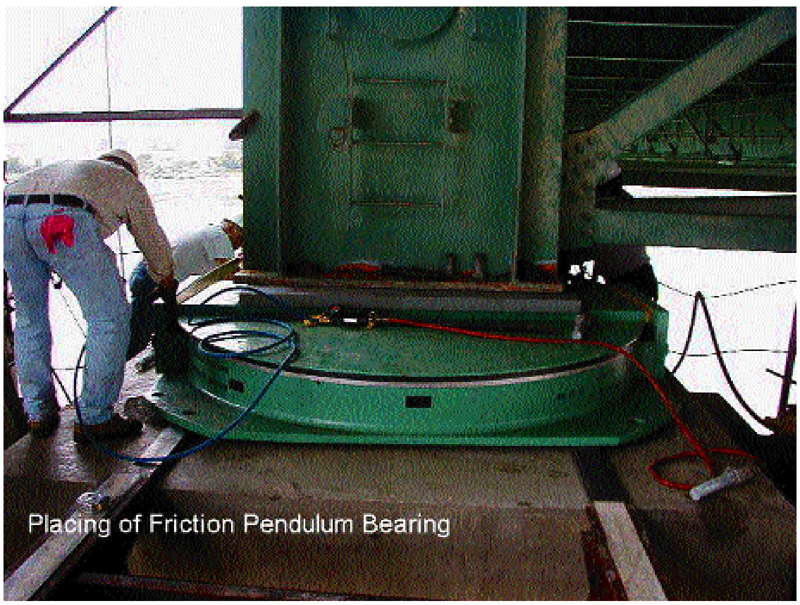
Isolation Bearings
Friction PendulumTM bearings, fabricated by Earthquake Protection Systems (EPS), are on the leading edge of innovative seismic design. Applications have included building and industrial facility construction as well as bridge construction. Currently, the Hernando Desoto Bridge incorporates the largest vertically loaded friction pendulum bearings in the world. Friction pendulum bearings consist of three major components:

- A top guide plate, which is mounted to the superstructure

- Concave bottom plate, which is mounted to the substructure

- An articulated slider, which is fitted to the top plate and rests on the bottom plate

- During an event, the articulated slider will move along the concave surface of the bottom plate, which will guide the top plate (and connected superstructure and deck) in small pendulum motions. Due to friction, the pendulum motions will dampen and absorb a large amount of the damaging earthquake energy. This results in a reduction of lateral loads and of shaking movements throughout the structure.


Placing of Friction Pendulum Bearing

The main channel spans will require a total of 18 friction pendulum bearings. There are four sizes of pendulum bearings specified for the Hernando Desoto Bridge. Type 1 and 2 are the larger bearings and will support the tied arch spans. The Type 1 bearings (the largest in size) will have a maximum vertical load capacity of 12.6 million pounds, which easily qualifies as the largest vertical load capacity of any friction pendulum bearing in the world. The Type 1 bearings have an inside diameter of 8"-10", a bearing height of 1"-10", and can withstand a lateral seismic force over 1.3 million lbs. The smaller Type 3 and 4 bearings that support the steel box girder spans will allow up to 29" - 30" in seismic lateral displacement.

Twelve lead Rubber Bearings fabricated by Dynamic Isolation Systems have also been utilized in the Hernando Desoto Bridge retrofit. Lead Rubber Bearings have been installed on over 100 Bridges and 70 Buildings and have proven their effectiveness during the 6.7 earthquake in Northridge, California in 1994. The University of Southern California Hospital was supported on Lead Rubber Bearings, and although it was in a severely damaged area, the hospital suffered no harm to the structure or any of its contents.

Lead Rubber Bearings consist of a pure lead core cylinder closely surrounded by layers of rubber and steel that are bonded together. Under normal loads the rubber allows lateral and longitudinal displacements while the steel plates strengthen the bearing vertically and the lead core strengthens laterally against wind and other non-seismic loads. During an earthquake event, seismic loads will cause the rubber and steel layers to push and deflect the lead core laterally, which dampens and dissipates the earthquake's damaging energy. These bearings can withstand a 550,000-lb lateral load and a lateral displacement of 22.5" during an event.

Current Construction Status - Main River Channel Spans

The first contract for work in the main river channel on the Hernando Desoto Bridge was awarded to Massman Construction Company in December 1999 and was completed in January 2003. Two additional contracts for work in the main river channel were also award to Massman in December 2000 and December 2002. Work under these contracts continues to progress rapidly. The December 2000 contract is expected to be completed by spring of this year. The December 2002 contract is projected to be completed by the end of 2005.

Column Cap Retrofit

On the main river channel spans, sixteen of the eighteen friction pendulum bearings and all twelve Lead Rubber Bearings have been installed to date. The remainder of the friction pendulum bearings will be fully installed by this spring. All of the new bearings have been installed while maintaining traffic on the bridge through the use of hydraulic jacks. Hydraulic jacks with vertical lift capacities from 5 to 12 million tons have been placed on either side of the existing bearings, and have been set to lift and support the bridge while the existing rocker bearings are removed and new isolation bearings are installed. Stiffener plates and other strengthening components have been added at several locations to provide adequate jacking points.

Many of the column caps were extended to accommodate the new bearings. Four of the webwalls were also retrofitted. The webwalls were extended vertically and connected to the column caps.

The superstructure and deck work was performed while maintaining 4 lanes of traffic at all times. (The Hernando Desoto Bridge maintains 6 lanes of traffic under normal conditions.) The existing finger joints have been replaced with swivel joints, which will allow for 22.5" of longitudinal movement and 18" of transverse movement during an earthquake.

Additional superstructure retrofit items includes strengthening diaphragms, adding direct connections between the deck and box girders, stiffening the connections between stringers and the floor beams, and replacement of cross frame and lateral bracing members. The contractor utilized a moveable suspended work platform to perform the majority of the superstructure retrofit. The platform allowed work to be performed from underneath the structure rather then from above which would have require removing large portions of the deck.

Swivel Joint Installation

Steel Superstructure Retrofit Using Suspended Platform

Footing and column strengthening has also started in the main river channel. Currently, two footings have been retrofitted and another two are expected to start in the near future. Cofferdams are required to perform the work "in the dry". The cofferdams used are some of the largest cofferdams ever constructed in the State of Tennessee standing up to 55 feet above the riverbed. The footing encasements consist of approximately 2400 yards of concrete and were poured continuous over approximately a 12-hour period.

East Approach Spans

Outside of the main river channel, construction is also underway on five East approach spans. The contract for this work was awarded to Dement Construction Company in October 2001. Currently, the contractor is performing ahead of schedule, and work is expected to be complete by spring of this year.

The retrofit work under this contract on the substructure includes footings, columns, and pier caps strengthening. The footings have been strengthen by installing cast-in-drilled-hole (CIDH) piles around the perimeter of the existing footing, drilling and bonding bars to the existing footing, and then forming and placing reinforced concrete to incase the new piles, bonding bars, and the existing footing. Drilling for the CIDH piles was achieved despite vertical limitations using a low clearance drill. The columns have been retrofitted by erecting a steel casing around the existing column, and then forming and placing reinforced concrete between the existing column and the steel casing. The pier caps have been strengthen by casting reinforced concrete around the existing cap to increase the cap width.

Retrofit work will also include replacing the existing bearings with Disktron Bearings and strengthening the existing cross frame system. The Disktron Bearings were custom designed for this application and will be supplied by R.J. Watson, Inc. The system basically consists of an upper and lower bearing plate which are mounted to the superstructure and rest on a slide plate. The bearing plates (with the superstructure) are allowed to move longitudinally across the slide plate up to 12", but are restrained in the lateral direction. The Disktron Bearings are design to withstand a maximum vertical load of 160,000 lbs, transverse load of 250,000 lbs, longitudinal load of 70,000 lbs and an uplift load of 10,000 lbs.

The existing cross frame system will be removed and replaced. The new cross frame, located at every pier location, will consist of built-up steel I-beams bolted between each steel girder and drilled and bonded to the bridge deck. Shear blocks will also be installed at several locations in order to control lateral movements during a seismic event.

Seismic Monitoring
In conjunction with the seismic retrofit work, The University of Memphis will install a seismic instrumentation system to monitor the behavior of the Hernando Desoto Bridge during an event. The system consists of 114 sensors at 38 different chosen locations on the main channel spans. This will be the first existing long span bridge in the New Madrid seismic zone to be instrumented for seismic monitoring. The data collected from the sensors under small events will be used to verify or enhance the current mathematical models used for to predict movements under the larger seismic design events. This will not only improve predictions of the seismic behavior of this particular bridge, but can also be used to advance seismic codes and future seismic bridge designs.

Work on the Mississippi River Bridge has already made this project a pioneer in seismic design and construction. Upon completion, the bridge will safely endure a magnitude (mb) 7 earthquake with little to no damage. Presently, almost $72 million of combined state and federal funds have been invested for the construction of this project. It is expected to take an additional $102 million to complete the project. TDOT, AHTD and FHWA are working closely to achieve goals that can benefit the transportation system as a whole. What will be achieve through this seismic preparedness project, will benefit the region and sustain a vital embrace in the event of an earthquake. This is another great example of how new technology and team work within the transportation community can build a healthier future. •

Be sure to visit the Hernando Desoto Bridge when you attend the National Seismic Conference in Memphis, February 2004.

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